PHOSPHORUS FERTILITY RELATIONSHIPS OF CENTRAL WASHINGTON IRRIGATED SOILS

With Special Emphasis on Exposed Calcareous Subsoils

WASHINGTON AGRICULTURAL EXPERIMENT STATION COLLEGE OF AGRICULTURE

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D. W. JAMES, G. E. LEGGETT, AND A. I. DOW

SUMMARY AND CONCLUSIONS

To facilitate irrigation in central Washington, land is leveled or smoothed on a broad scale. As a result, the calcareous and extremely infertile subsoils are exposed and used directly as a medium for plant growth. Phosphorus fertilizer requirements of exposed subsoils were determined by measuring crop yield and P uptake on plots that were fertilized in the current and one, two or three preceding seasons. Annual crops used as indicators of P availability at three sites were field beans, Sudangrass and sugar beets. A supplementary experiment involved fertilization of a previously established alfalfa crop. Crop growth and P uptake results were correlated with sodium bicarbonate soil testing.

It was shown that calcareous subsoils can be as productive within the first season after exposure as their related noncalcareous surface soils. To accomplish this, extraordinarily large amounts of phosphorus were required—up to 130 lb P/acre (662 lb/acre of concentrated superphosphate, 0-45-0). Pronounced residual fertilizer effects were measured four crop seasons after fertilization and much longer residual effects are anticipated. The soil test P index proved to be reliable for predicting soil P availability. Thus, an economically sound and practical method for re-establishing the productivity of cut lands is:

1. Use soil test as a guide.
2. Plow down large applications of P fertilizer at the outset.
3. Apply P as needed in subsequent seasons to maintain the soil test P index above 20.

A summary of 37 field experiments conducted over the period 1957 to 1966 is given. This summary shows that soil test P is a reliable indicator for predicting the need for supplemental P and for evaluating the residual effect of P fertilizer.

INTRODUCTION

Most of the surface soils in central Washington are noncalcareous but are underlain by materials that contain free calcium carbonate or lime. Lime begins at depths of 2 to 30 inches and, although the amount is not constant, it is usually continuous throughout the subsoil profile. To facilitate irrigation, newly developed lands in this area are leveled or smoothed on a large scale. The deep cuts and fills that are made often completely remove the noncalcareous surface soil from portions of the land. The calcareous subsoil is thus exposed and used directly as a medium for plant growth.

Preliminary investigations and farmers' experience have shown that the phosphorus fertility relationships in these calcareous subsoils are far different from those of the undisturbed surface soils in the area. In some instances 130 lb P/acre[1] was required to grow satisfactory crops on these soils. This rate of phosphorus is considered very high, even for acid soils, which are noted for P fixation. Coupled with these observations was a question on the interpretation of the phosphorus soil test value. Some farmers have found that after heavy applications of P fertilizer to the exposed calcareous soil, the soil test was still low, yet only moderate amounts of P were required for good crop production in the second season. Experimentation was begun in 1962 to answer these questions. This bulletin presents some of the results.

[1] Throughout this text, all data and discussions on phosphorus will be in terms of elemental P rather than the oxide, P_2O_5. Washington State University has used the elemental designation for several years in plant analysis and soil testing work. We are now using the elemental designation for fertilizers too. For comparison, the reader can convert pounds P to pounds P_2O_5 by multiplying by 2.29. To convert P to concentrated superphosphate equivalent (0-45-0), use the factor 5.09. Thus 100 lb P is the same as 229 lb P_2O_5 or 509 lb concentrated superphosphate.

REVIEW OF LITERATURE

Historical

Phosphorus fertilization has been investigated since the earliest days of research in Washington's arid-region agriculture. A 12-year productivity study was started in 1922 on the Sagemoor fine sandy loam. (This soil series is now referred to as Warden.) Crop responses were observed with such phosphorus materials as concentrated superphosphate and bone meal (36). Yield increased most when nitrogenous materials were applied but it may be inferred that responses to phosphorus were obtained also from such materials as fish scraps and manures. A later report (37) stated that phosphorus fertilizers caused outstanding yield increases on the same soil type "except when used on new land or on areas where large applications of manure had been applied."

Detailed investigations were made on the behavior of phosphorus in the Sagemoor soil. Movement of phosphorus from band-placed fertilizer was negligible. Stanberry (38) concluded that although phosphorus is immobilized in the Sagemoor soil, it is not rapidly fixed into unavailable forms. He also discussed the effect of crop removal of phosphorus and the concomitant decrease in soil phosphorus level.

In a study of several chemical forms of fertilizer phosphorus, fertilizing with phosphoric acid and concentrated superphosphate gave the highest alfalfa yield (19). Other forms of phosphorus such as calcium metaphosphate or dicalcium phosphate were either less effective or cost more than concentrated superphosphate. Radioactive P^{32} fertilizer was applied to the Sagemoor soil to help describe the pattern of phosphorus uptake by crops. Where no crop response was obtained, only 2 to 3% of the P absorbed by the alfalfa originated in the fertilizer. In another case, where a fertilizer response was obtained, 30 to 35% of the P taken up by the crop came from the fertilizer.

Over the years, soil fertility research and demonstrations were conducted throughout irrigated central Washington. The accumulated information formed the basis for soil fertility management. When the Columbia Basin Project brought new lands under irrigation, the experience in older areas was generally applicable. But the land leveling created a new kind of soil fertility management problem. Nelson and Crawford conducted a preliminary investigation on the fertility of cut lands (30). Largely the Outlying Testing Program conducted and reported by Dow (9, 10, 11, 12) revealed the real nature of the problems involved in cut land management.

Subsoil Productivity

Land leveling to facilitate irrigation, with the resulting exposure of subsoil, is not uncommon in the western United States. Whereas subsoil is generally less fertile than undisturbed surface soil, no special problems have been recognized elsewhere in restoring the productivity of leveled land. In both Colorado and Montana, a variety of crops grown on exposed calcareous subsoils had normal yields (42, 34). The amounts of phosphorus required were not excessive and good yields were obtained in a short time. Black and Whitney (4) studied the inherent fertility of the genetic horizons of four soil series by means of pot tests in the greenhouse. They reported that, with adequate N plus P fertilization. 16 of 21 subsoil horizons yielded as much or more than their respective surface soils.

Phosphorus Relationships in Calcareous Soils

The term calcareous refers to calcium and magnesium carbonates or lime. Qualitatively, a soil is considered to be calcareous if it effervesces or releases carbon dioxide upon treatment with strong acid, but small amounts of lime may escape detection by this procedure. Soil paste pH increases from 7.0 or 7.5 to about 8.1 as the lime content increases from zero to about 1%. Increasing amounts of lime will not raise the pH above 8.1 or 8.2. Most arid-region soils contain some lime, as do some humid-region soils that have calcareous parent material. Phosphorus fertilization of calcareous soils has been experimented with extensively throughout the West (15, 27, 29, 33, 35, 38). The evidence indicates that lime in the soil should not be considered a particular handicap in managing phosphorus soil fertility.

The consensus of the foregoing research reports is that there is a pronounced residual effect of phosphate fertilizer of up to 6 years, depending on the conditions. Although phosphorus is not mobile in the soil, loss of P in calcareous soils by chemical reversion to unavailable forms (fixation) is not considered to be serious.

Using orthophosphoric acid and monocalcium phosphate monohydrate as reference materials, many chemical forms of phosphorus have been tested for their utility as sources of fertilizer phosphorus. Hausenbuiller and Weaver (19) compared calcium metaphosphate, dicalcium phosphate, fused rock phosphate, and raw rock phosphate with the standard forms. In addition to the above compounds, other workers tested nitro-phosphates, ammonium phosphates and tricalcium phosphate (15, 31). A study of nine different phosphorus compounds included calcined phosphate (heat treated alkaline phosphate) with the standard materials (35). Beaton and Nielsen (1) studied 12 different types of phosphorus including hydroxyapatite and various ammonium phosphates.

Beaton and Read (2) included ammonium taranakite in a comparison. A report on many tests in several states discusses results with calcium metaphosphate and potassium metaphosphate (40). Terman et al. (41) tested six pure crystalline forms of P that included the standard forms and both the anhydrous and dihydrate forms of dicalcium phosphate. Hagin (16) studied potassium metaphosphate.

The results of all the foregoing investigators can be categorized, in a manner analogous to that of Haddock et al. (15) according to the ability of the various phosphorus materials to increase P uptake and crop growth. Broadly speaking, the categories are:

1. *Water soluble.* Standard forms are phosphoric acid and mono-calcium phosphate monohydrate (concentrated superphosphate). Other forms that compare with the standards are ammonium phosphate and ammonium polyphosphate. This group is almost invariably superior to any other group for calcareous soils.
2. *Slightly water soluble.* Calcium metaphosphate and potassium metaphosphate. These materials may perform as well as group 1 under some conditions, but in the field may require 1 year following application to achieve best results.
3. *Water insoluble.* Dicalcium phosphate dihydrate (citric acid soluble phosphate). Certain kinds of ammoniated phosphates fall into this group. These materials may equal the standard forms when finely dispersed and thoroughly mixed in the soil. Probably, they will not bring about the best results under ordinary farming conditions.
4. *Apatite-like materials.* Raw-rock phosphate and some reaction products of P in the soil. This group rarely if ever increases P uptake or crop production on calcareous soils.

MATERIALS AND METHODS

Field Experiments

Two experimental sites (F-38 and D-1) were chosen on the Roza unit of the Irrigated Agriculture Research and Extension Center, 7 miles northeast of Prosser. A third site (B-15) was in Irrigation Block 15 about 6 miles west of Eltopia. The soil at the Roza sites is Warden fine sandy loam and at the B-15 site, Taunton sandy loam. General descriptions of the Warden and Taunton soils are available (14). Leveling removed 2 to 3 feet of soil from the experimental area at the B-15 site. The exposed subsoil is a calcareous fine sandy loam with no restrictive layer within 6 feet of the new land surface.

Roza field F-38 was adapted for this research by removing the top 14 inches of soil from 1 acre of land. The exposed subsoil is a calcareous silt loam underlain at about 3 feet by basalt bedrock. Roza field D-1 is a noncalcareous surface soil, undisturbed except for tillage. The subsoil is calcareous and is underlain at about 5 feet by basalt. The latter site was included for comparison. Some descriptive data for the three sites are in table 1. According to the standards used by the WSU Soil Testing Laboratory, these soils would be classified as follows for P: B-15 and F-38, extremely low; and D-1, low. Table 1 shows that the soil test index tends to increase just above the bedrock at F-38. The same kind of variation occurred at D-1 but not at B-15.

A scheme of fertilizer treatments was developed to compare applied phosphorus rates, both within and between seasons. This procedure is somewhat analogous to that of Eik et al. (13). Beginning in 1962, various rates of P were applied to certain plots in each experiment. The same rates of P were applied to previously unfertilized plots in 1963 and 1964. Thus, in 1963 and 1964 the residual effect of P applied in previous years could be evaluated in terms of the current year's applications. In addition, treatments were included to evaluate the accumulative effect of yearly applications, the source of concentrated superphosphate, and the method of application. These comparisons were made at the assumed optimum rate of P fertilization. The criteria used for evaluating the treatments were yield, P concentration in the crop, and yield of P. Treatment details are in table 2.

The experimental design was a randomized complete block with three replications at F-38 and four replications at the other two sites. The field plots were 14.7x30 ft. This allowed for 8 crop rows, each spaced at 22 inches. Plant tissue samples and yield samples were taken in a way that avoided border effects.

Table 1. Calcium carbonate equivalent and soil test P before treatment in the surface soil and soil test P in subsurface layers at three locations

Site	Depth	$CaCO_3$ equiv.	Soil test P[a]
		%	pp2m
B-15	0-8 inch	2.4	1.4
	0-1 ft	[b]	1.1
	1-2 ft	-	0.8
	2-3 ft	-	1.2
F-38	0-8 inch	4.6	1.3
	0-1 ft	[b]	1.2
	1-2 ft	-	0.8
	2-3 ft	-	3.4
D-1	0-8 inch		8.8
	0-1 ft		8.2
	1-2 ft	[b]	1.9
	2-3 ft	-	1.4

[a] Replication means.
[b] $CaCO_3$ is continuous in sub-layers varying up to 5% in amount.

Table 3 summarizes cropping and management according to year and site. The broadcast fertilizers were incorporated into the soil by rototilling at D-1 and F-38 in 1962 and at all sites in 1963 and 1964. The fertilizers were broadcast before plowing at B-15 in 1962 and at all sites in 1965.

Plant tissue samples from each plot for chemical analysis consisted of:

1. 10 whole bean plants.
2. 15 whole sudangrass stems including leaves at each harvest.

Table 2. Treatments and time of application

Treatment no.	Year	P applied—lb/acre B-15 and F-38	Field D-1
1	1962,3,4	0	0
2	62	33	11
3	"	66	22
4	"	132	44
5	"	264	88
6	63	33	11
7	"	66	22
8	"	132	44
9	"	264	88
10	64	33	11
11	"	66	22
12	"	132	44
13	"	264	88
14	62	132	22 (reagent grade P)
15	"	0	
16	62,3,4	132	44
17	"	132	
18	62	132	
19	"	33 (b)	
20	"	132 (b)	

Notes:

Banded treatments 19 and 20 were utilized at the B-15 site only and only in 1962. Treatments 15-18 included a K fertilizer variable.

Treatment 15 received 264 lb P/acre at B-15 in 1965.

P was in form of concentrated superphosphate.

3. 20 most recently matured beet petioles at mid-season and whole top plus crown at harvest together with pulp samples of harvested roots.

Yields were measured as follows:

1. Beans, four center rows 26 ft. long, dried and threshed.
2. Sudangrass, area 6x25 ft. cut and weighed with subsample for moisture determination.
3. Beets, three subsamples of roots per plot each consisting of measured 15 ft. of row. The beet subsamples were selected in each plot so as to have a near-perfect stand of beets in the harvest row and in the two adjacent rows. The roots were washed, weighed and sampled for pulp using the Spreckels saw. The pulp samples were analyzed for sugar and P content.

A supplementary experiment involving alfalfa production on calcareous subsoil was set out in March 1965. The location is in the southwest part of the Quincy basin (Irrigation Block 77). The soil in this area is a complex of several series; the soil at the experimental site seems to fit the description of Koehler series (14). On the surface, the soil is a loamy sand-sandy loam. The subsurface is a calcareous fine sandy loam. The field had been leveled and, in the experimental area, depth to caliche was 2 to 3 ft. Fertilizer treatments were applied as a top-dress to the 1-year-old alfalfa crop. Before the experiment, soil test P was 1.5 with essentially no variation in soil test with depth.

Concentrated superphosphate was applied at rates of zero, 22.5, 45, 90 and 135 lb P/acre. For the P rates, B and K were uniformly applied at 3 and 100 lb/acre, respectively. Hay crops were harvested in two seasons as follows: 1965—May 21, July 12, August 31; 1966—May 23, July 13, and August 29. Plant samples before

Table 3. Annual record of crops and crop management practices

Year	Test crop	Location	Supplementary Fertilizer N	Zn	K	Plant date	Harvest date(s)
1962	Field beans,	D-1	0	10	80	June 1	October 10
	var. Red Mexican 15	F-38	120	10	80	"	"
		B-15	120	10	80	"	"
1963	Sudangrass,	D-1	40	10	0	May 20	July 16, Aug. 16, Oct. 4
	var. Piper	F-38	80	10	80	"	" " "
		B-15	80	10	80	"	July 25, Aug. 30, Oct. 17
1964	Sudangrass,	D-1	100	0	0	May 10	July 13, Aug. 24, Oct. 15
	var. Piper	F-38	120	0	0		" " "
		B-15	120	0	200		July 22, Oct. 8
1965	Sugar beets,	D-1	0	0	0		
	var. Commercial	F-38	200	0	0	April 1	Oct. 27
	hybrid	B-15	200	0	200	April 12	Oct. 25

Notes: Zinc as zinc sulfate in 1962 and as ZnMnNS in 1963. K as KCl. Nitrogen as ammonium nitrate.

Supplemental applications of nitrogen at 100 lb/acre were made to Sudangrass both years after both first and second harvests at F-38 and B-15.

Beans and beets were planted in 22-inch rows with irrigation water applied in rills in every row. Sudangrass was planted in rows 6 inches wide with rills spaced at 36 inches for irrigation.

each harvest consisted of 20 stems per plot, the top 3/4 of the whole stem. Plot size was 10x30 ft. Yield was estimated by clipping an area 3.5x23 ft. from each plot. The fresh forage was weighed and sub-sampled for moisture determination.

Irrigation at all locations was by the rill method and no known moisture stress occurred in any season.

Laboratory Methods

All plant materials were analyzed for total P by nitric-perchloric acid digestion and colorimetric P determination by the vanado-molybdate method (22). Phosphorus analysis of the soils was by the bicarbonate method of Olsen et al. (32) except that the soil-solution ratio for extracting P was 1:10 rather than 1:20.

RESULTS

The results of 5 years' experimental work are presented in two sections. The first section emphasizes crop yield and P uptake in the four-season study with annual crops and the supplementary study with alfalfa. In some seasons, certain unforeseen or otherwise uncontrolled factors affected crop yield. These factors are described with the results in each season. They must be well understood for proper assessment of the meaning of the data. The second section presents the effects of fertilizer application and crop removal of P on soil test P index, together with the associations between soil tests and crop growth parameters for the annual crops. Salient features of the research results are in graphs and tables. Most data are in the appendix.

Crop Yield and P Uptake

Beans, 1962

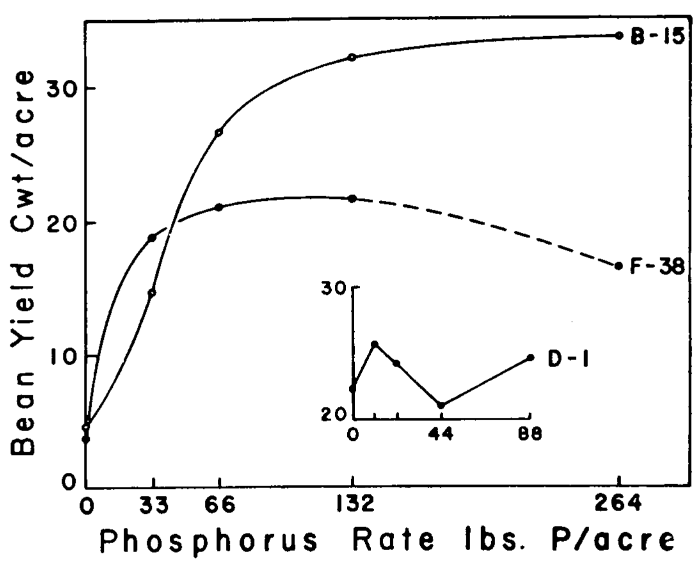
The 1962 responses of beans to P fertilizer are in figure 1. Very poor production with zero fertilizer phosphorus at the two calcareous soil sites emphasizes the extremely low natural levels of available P in these subsoils. The results also indicate a considerable difference between the Warden and Taunton soils in this respect; 66 lb of P/acre were required for maximum yield at F-38 while 132 lb of P/acre were required at B-15. The yield for highest P rate at F-38 is believed to be spurious and is so indicated by the dashed line. The value for one replication of this treatment was very low for some unknown reason. Results at D-1 indicate no yield differences because of phosphorus fertilizer.

In comparison with commercial bean fields, the best yield level at F-38 was only fair; that at B-15 was excellent. Two factors might explain the difference between the two calcareous sites. First, the soil test P tended to increase in the 2-3 ft layer at F-38 (table 1), indicating an increase in availability of indigenous soil P with depth. Second, beans had been grown at the F-38 site in 1955. Although the original surface soil had been removed for the 1962 experiment, it is known that inoculation of the soil by bean diseases (e.g. fusarium root rot) can occur at depths of 3 ft.[2] Disease could account for the much earlier maturity and earlier leaf drop at F-38 and the lower yield of beans. P contents of the bean crops were the same for the two calcareous sites at the optimum fertility levels (figure 2). Crop yields in subsequent seasons show the two sites were similar in overall productivity.

Yield results from special P sources (TVA concentrated superphosphate and reagent grade monocalcium phosphate) were comparable to those from the regular source of P. Thus, the possibility that part of the response was due to minor element contamination of the western P fertilizer is considered unlikely.

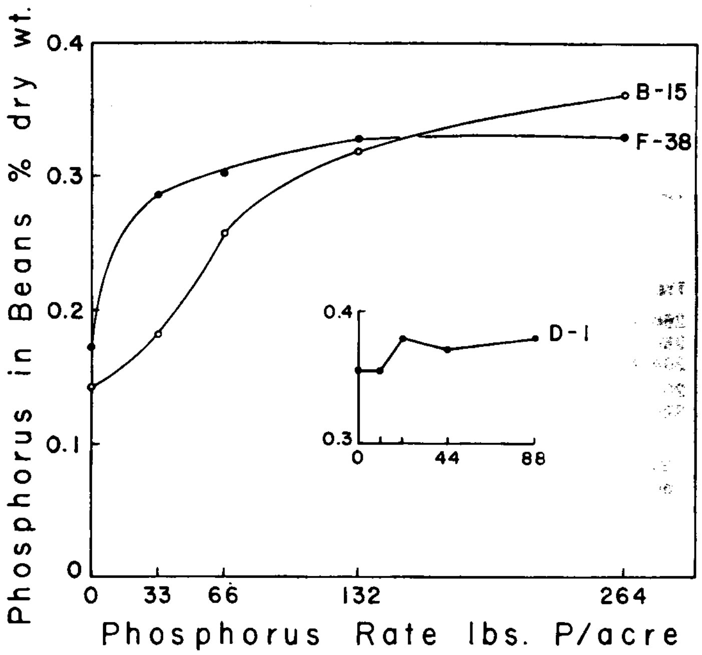
Results for P uptake in figure 2 indicate that maximum or near maximum bean yield corresponds to 0.30 to 0.35% P in the whole plant at mid-season. Treatments had very little effect on P content at the D-1 site. The difference in P content curves between the two calcareous sites points out a rather sharp distinction between these two soil series. The increase in P availability with depth at F-38 (table 1) could account for some of this difference.

The evidence from all sites indicates that a well nourished bean crop contains 15 to 25 lb P per acre.



1. Effect of phosphorus fertilizer on yield of dry beans at three locations. Data points in all figures are replicate means.

[2] Personal communication from D. W. Burke.



2. Effect of phosphorus fertilizer on phosphorus content of beans. Whole plant was sampled August 1.

Comparisons for band and broadcast applications of P fertilizer for beans grown at B-15 in 1962 are in table 4. The data indicate that banding offers no advantage over broadcasting and plowing under the lower rates of P fertilizer. At the low rate of P, bean yields resulting from the two methods of application were about equal. Early in the season, the foliage contained much more P where the P was banded, but the difference evened out before harvest. On the other hand, broadcasting the high rate of P resulted in higher bean yield than did banding. This difference was not predicted by the P contents of plants sampled before harvest.

Sudangrass, 1963 and 1964

Sudangrass production in 1963 at the two calcareous sites was adversely affected by uneven availability of N because of fertilizer N residue from the 1962 treatments. (In 1962, only plots receiving P received N.) The 80 lb N/acre initial application was not sufficient to overcome the N variability in 1963. Subsequent N applications in 1963 and 1964 did eliminate this variation

Table 4. Effect of application method and P rate on P content and yield of beans, B-15 site

Treatment	Per cent P—whole plant July 11	Aug. 1	Sept. 6	Yield cwt/acre[a]
Zero P	.13	.14	.14	4.2
33 P broadcast	.16	.18	.16	14.7
33 P banded[b]	.27	.22	.16	16.8
132 P broadcast	.30	.32	.25	32.2
132 P banded[b]	.27	.28	.25	24.8

[a] 132 P broadcast differs from 132 P banded. No difference between 33 P broadcast and 33 P banded.
[b] Material applied 6 inches deep and 6 inches from the plants.

Another problem encountered with the Sudangrass was iron deficiency, "lime-induced chlorosis." The iron deficiency was especially severe on re-growth immediately following harvest, and deficiency tended to be most severe on plots with high levels of available P. Thus, the yield responses to P were confounded by the effect from iron. Iron sulfate solution applied to the foliage only partly corrected the deficiency.

The effect of time and rate of P application on Sudangrass yield and P uptake are summarized briefly here. The data are in the appendix. Despite the variability caused by N in 1963 and by iron deficiency in 1963 and 1964, response to P was significant at both calcareous sites for the P applied in every season. High residual availability is shown by the fact that the response to P applied the previous season exceeded the response to P applied in the current season. The patterns for growth and P uptake were similar.

The problems caused by N and iron at the calcareous sites were not encountered at D-1. At this site, response to P was significant in 1964 but not in 1963. Using P uptake at D-1 as a guide, it is apparent that each ton of Sudangrass forage (dry weight) contains about 4 lb of P. The grass will remove about 20 lb P/acre per year, according to the yield levels observed here.

Sugar Beets, 1965[3]

As indicated before, the noncalcareous D-1 site was discontinued after 1964. Figures 3 and 4 show yields of sugar beet roots and per cent P in the petiole at the two calcareous sites. Yield results from F-38 appear to indicate a wide difference between years of P application. However, the yield of roots at this site does not provide a true measure of P availability. This is because certain plots were deficient in sulfur, a condition in sugar beets that had not been recognized before in central Washington. Sulfur deficiencies in alfalfa have been reported from this area (5).

The S problem at F-38 was diagnosed in late July and a blanket treatment of gypsum corrected the symptoms but did not eliminate the variation caused by the deficiency. Details of the diagnosis, along with a discussion of S nutrition relationships of the crop, have been reported (23).

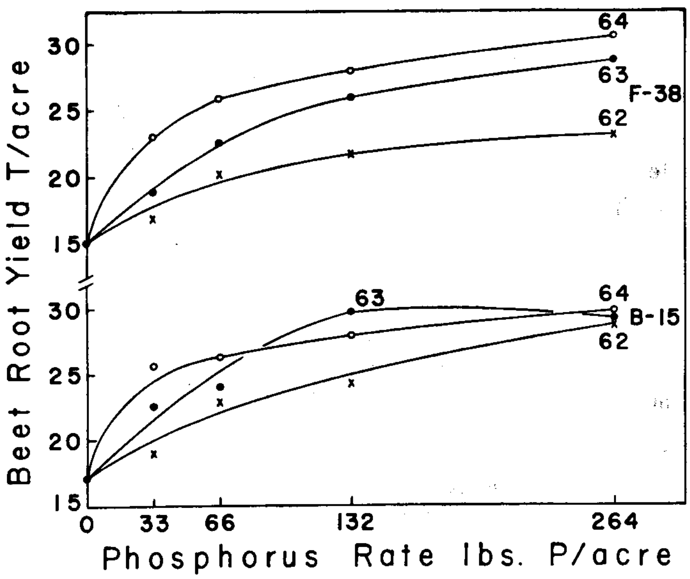
Whether or not sulfur also affected the yields at F-38 in previous seasons has not been established. It is known, however, that sulfur deficiency did not occur in beets at B-15. The yield of roots was quite high on the zero P rate at both locations but the validity of this treatment is open to question. Although most of the beets were stunted from lack of P on the zero P plots, at least one beet in every subsample of roots was quite vigorous, indicating that its feeder roots may have

[3] The cooperation of Mr. D. C. Kidman (Research Agronomist, Utah-Idaho Sugar Company, Toppenish), in the work on sugar beets is gratefully acknowledged.

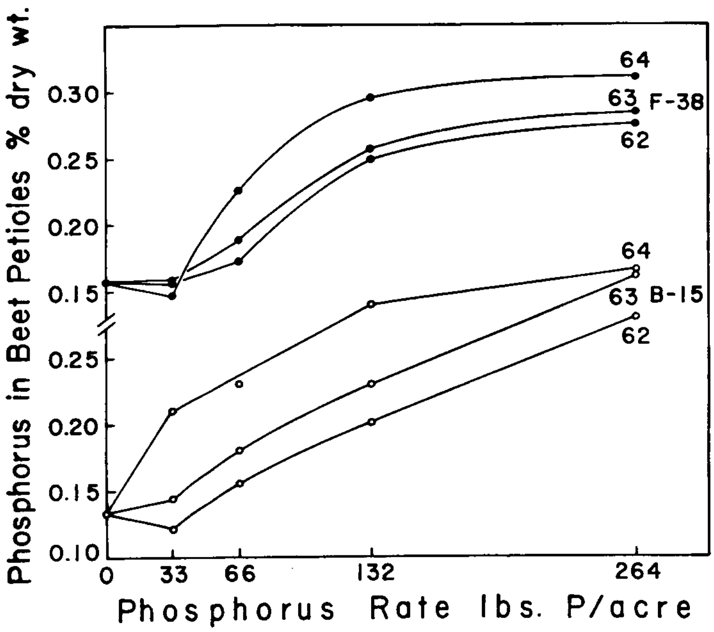
been in some very localized P. Probably, plowing and tilling caused a small amount of P contamination from other plots over the years.

With regard to P responses per se, there were significant yield increases from P applied in every season at each site. At B-15, yield increased slightly (1.5 tons/acre) from just 33 lb P/acre applied four crop seasons earlier. The pattern of per cent P in figure 4 is about the same as would have been predicted on the basis of prior seasons' results.

Beet yield results from the 264 lb P treatments and the cumulative 132 lb P treatments are summarized in



3. Effect of phosphorus fertilizer rate and year of application on yield of sugar beets, 1965.



4. Effect of phosphorus fertilizer rate and year of application on phosphorus content of beet petioles (sampled June 30).

table 5. Results at F-38 are, of course, confounded with sulfur deficiency. At B-15 there is a trend toward greater yield with the more recent applications. But in the analysis of variance, none of the differences are significant by individual degree of freedom tests.

Table 5. Influence of single doses of 264 lb P/acre and of 396 lb P/acre applied over a 4-year period on sugar beet yield in 1965

Treatment	Yield of roots, B-15	tons/acre[a] F-38
264 P in 1962	28.2	23.4
264 P in 1963	29.1	28.7
264 P in 1964	29.8	30.8
264 P in 1965	29.7	
396 P (132 each in 62, 63, 64)	30.8	27.2

[a] Yield differences not significant at B-15. Differences at F-38 are attributed to sulfur deficiency.

A comparison between per cent P in the beet petiole at midseason and yield (figures 12 & 13) indicates that sugar beet petioles should contain about 0.25% P on the dry basis for best yield. According to the results, a well nourished beet crop will contain about 20 to 25 lb P/acre, of which 35 to 45% will be in the roots. In other words, only about 10 lb P/acre will be removed by a beet crop if the tops and crowns are left in the field.

Since sugar content of beets is of primary importance, it might seem appropriate to relate P availability to sugar percentages. The data cannot be treated in this manner, however, because of the overriding influence of N on sugar content. Because of large differences in crop growth resulting from the variable P treatments and subsequent large differences in N removal, variable N levels had developed among the plots through the previous seasons. The effect of variable N was not evident in beet yields because adequate N was applied in 1965 to assure good growth in all plots. The per cent sugar in beets is more closely related to N than to P availability. The problem of controlling N availability for maximum sugar yield has been discussed elsewhere (21).

Alfalfa, 1965, 1966

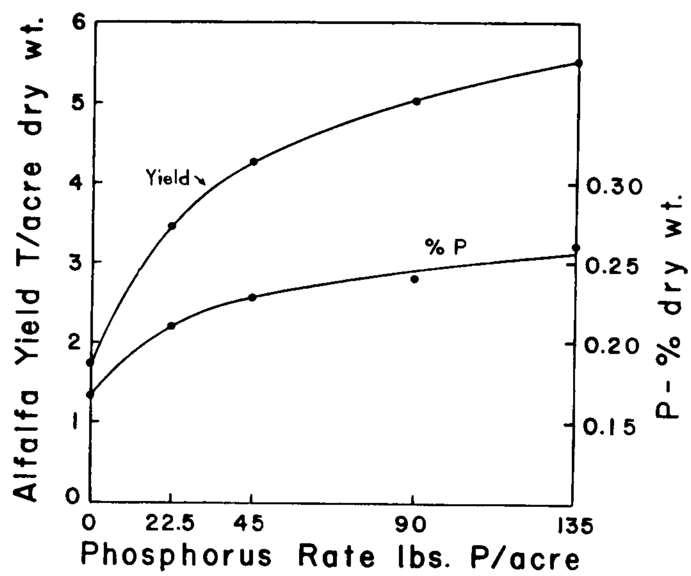
In the supplementary experiment on alfalfa, crop response to fertilizer P was evident within 2 weeks after alfalfa growth began in the spring of 1965 (about 1 month after fertilization). The results for yield and P uptake (figure 5) indicate an added response to each increment of fertilizer, but even the highest fertilizer rate did not completely overcome the P deficiency.

Since maximum alfalfa yield apparently was not attained in 1965, a certain group of plots that had originally received boron fertilizer[4] was used to provide an extension of the P treatments. These plots, which had received 90 lb P/acre in March, 1965, were given zero, 90 or 135 lb P/acre in November, 1965. Thus, the total

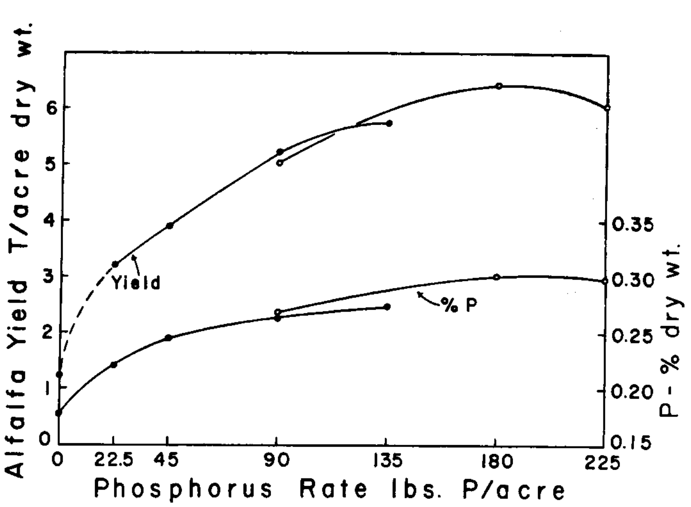
[4] B rates were zero, 3, and 6 lb B/acre. There was no growth response to Boron.

P applied for the two seasons was 90, 180, or 225 lb/acre. The 1966 results are in figure 6. Yield for zero P was difficult to estimate because of the paucity of plant material. Therefore, the season total yield for zero P was estimated from the first cutting only. This estimate was not included in the statistical analysis and so was indicated by a dashed line.

Figures 5 and 6 show that yield and P uptake results were very similar in the two seasons for the zero to 135 lb P/acre series. The data for the extended treatments, indicated by the open circles, show that yield and P



5. Alfalfa yield and phosphorus content responses to phosphorus fertilization, 1965.



6. Alfalfa yield and phosphorus content responses to phosphorus fertilization. Open circles are for supplementary P treatments in 1966.

content increased to the 180 lb P/acre fertilization. It is obvious from these results that alfalfa can use P that is at the very surface of the soil. It is also apparent that residual fertilizer effects were as pronounced as in the examples presented earlier for the annual crops.

There was considerable difference in levels of P between cuttings. But the results indicate that a well nourished alfalfa crop will contain roughly 6 lb P/ton of dry hay. At the higher yield levels shown here, the crop removes 35 to 40 lb P/acre per year.

Phosphorus-Soil Test Relationships

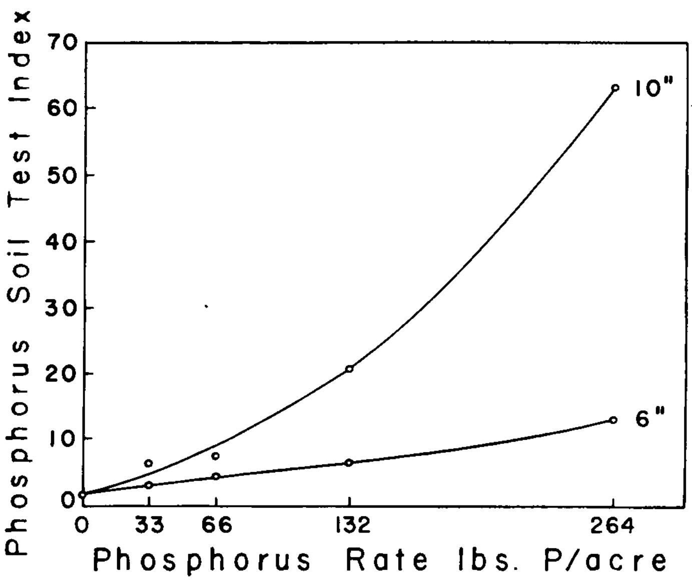
As stated in the introduction, a major objective in this research was to clarify some problems of interpretation of the phosphorus soil test index. Data in this section relate to the effect on the soil test index of P additions as fertilizer and P removal by crops. Also, phosphorus content of plants and crop yields are presented as functions of soil test P.

Effect of P Addition and Crop Removal on Soil Test

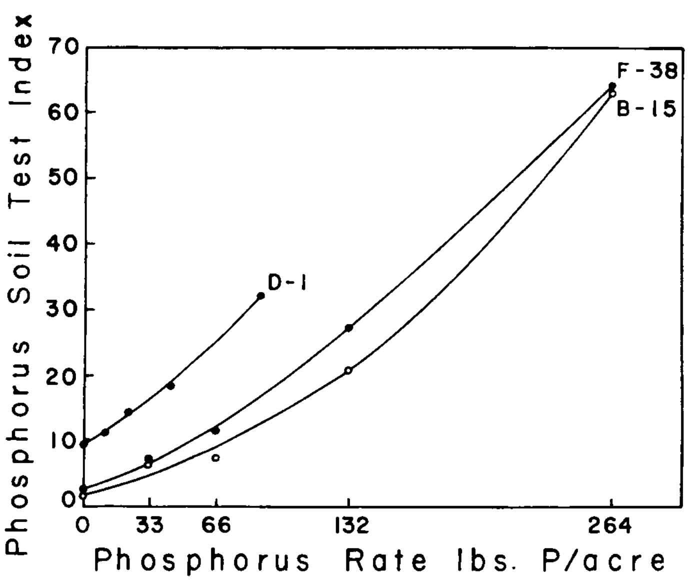
In November, 1962, following the first fertilization and cropping sequence, soil samples were obtained from field plots and tested for bicarbonate-soluble P. Soil samples were taken in a routine manner—15 to 20 cores per plot to a depth of 6 inches. Initially, the results obtained from B-15 were much lower than for comparable treatments at F-38. As mentioned before, in 1962 the fertilizer was applied at B-15 before plowing and without rototilling, whereas the soils at D-1 and F-38 were rototilled after fertilization. Close examination showed that the applied fertilizer was located near the plow-sole at B-15. The plow had an attachment for burying crop residue and this evidently skimmed the soil surface with the deep-set plow, pushing loose material on the soil surface to the bottom of the furrow. (Such a situation would not occur with shallower plowing or without the attachment.) When plots at B-15 were sampled to the 10-inch depth, the soil test results were much higher and were similar to those at F-38 (figure 7). These results point out one reason for the prevailing confusion in central Washington concerning reliability of sodium-bicarbonate-soluble P as a measure of P availability. As a result of this work, all soil samples were taken to a depth of 10 inches.

The 1962 soil tests for all three sites are shown in figure 8. Values obtained in 1963 and 1964 for the then current season's applications of P were analogous to those in figure 8. The slopes of the curves for the calcareous and noncalcareous sites are similar, indicating that the effect of applied P on the soil test is similar on both kinds of soil.

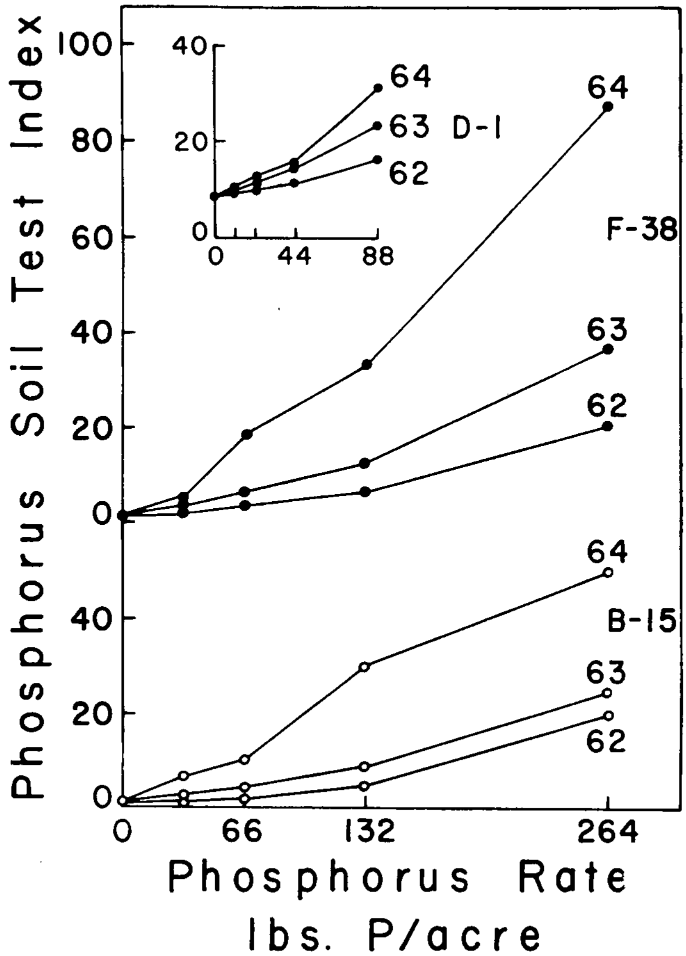
Soil test results after three complete cycles of fertilization and cropping are given in figure 9. The scatter of points for the 1964 P (in contrast to the smooth lines



7. Effect of sampling depth on soil test results, B-15 site, 1962.



8. Relationship between phosphorus soil test index and rate of fertilization. Fertilizer was applied April, 1962; soils were sampled November, 1962.



9. Effect of phosphorus fertilizer rate and year of application on soil test. Soils were sampled in late fall of 1964.

for the 1962 and 1963 P applications) is believed to indicate the degree of mixing or dispersion of the fertilizer P in the soil. That is, after rototilling, the P was still localized around the original fertilizer pellets. After being mixed by tillage in subsequent seasons, representative samples were more easily obtained. The test results for F-38 are in general higher than at B-15. This is not believed to be a distinctive difference, since other results show the two sites to be more nearly alike. There was much more change in soil test between the 1- and 2-year old P than between the 2- and 3-year old P at both sites.

Figure 10 shows the change in soil test values at the two calcareous sites for all rates of P applied in 1962 and sampled annually in the fall from 1962 to 1965. Curves for the two locations are very much alike. Again, the greatest change at each P rate was in the first season. The change between 1963 and 1965 for all rates except the highest was essentially zero. Soil test results two seasons after application for each fertilizer rate series are in table 6. The results appear to be quite uniform in view of the fact that histories and P removals were different for the respective treatment series. Fall and spring soil tests are compared in table 7. It is evident that sampling time had no effect on soil test P index.

The amount of P removed in each crop as related to time and rate of P fertilization is summarized in table 8. No clear correlation of the seasonal change in soil test P with crop P removal was found.

This kind of comparison is of course confounded by organic P remaining in the soil in roots and other crop debris. The effect of crop P removal on soil test P would have been easier to assess if a fertilized but uncropped treatment had been included in each experiment. This could also have shown the effect of time on chemical transformations of the fertilizer phosphorus. The dominant form of soil P (after equilibration of the fertilizer with the soil) was probably dicalcium phosphate. However, other inorganic forms not so well represented in the soil test procedure but which could contribute to the physiologically available P are probably present.

According to table 8, about 70 lb P were removed by four crops from the 264 lb/acre P applied in 1962. When this number is compared with figures 9 and 10, it is apparent that the re-application of 70 lb P/acre would not raise the soil test to the level obtained in the fall of 1962. It is obvious from all these results that the total change in soil test P cannot be accounted for by crop removal of P.

Association of Crop Per Cent P and Yield with Soil Test

The best opportunities for soil test correlation are with the 1964 Sudangrass and 1965 sugar beets. For the Sudangrass, the relative yields for the two calcareous sites are compared with soil tests from the plots that received P in 1962 and 1963. The results are given in figure 11. The problem of iron chlorosis reduced the degree of the association. This is particularly evident for the 80% yield point at soil test value 51. This treatment was severely affected by iron deficiency. Otherwise, the correlation between yield and soil test is fairly good. The association between per cent P in the Sudangrass and the soil test was poor. Therefore, no attempt was made to demonstrate this relationship.

Table 6. Effect of fertilizer rate on soil test P two crop years after fertilizer application

P rate, lb/acre	Year P was applied 1962	1963	1964
	Soil test Pindex 2 years later		
Site B-15			
33	2.1	2.4	4.6
66	4.5	4.1	6.2
132	5.4	8.5	10.2
264	26.1	25.0	27.4
Site F-38			
33	2.4	3.3	3.6
66	4.0	6.7	6.4
132	12.1	12.7	13.0
264	28.8	37.1	25.0

Table 7. Effect of time of soil sampling on soil test index—F-38

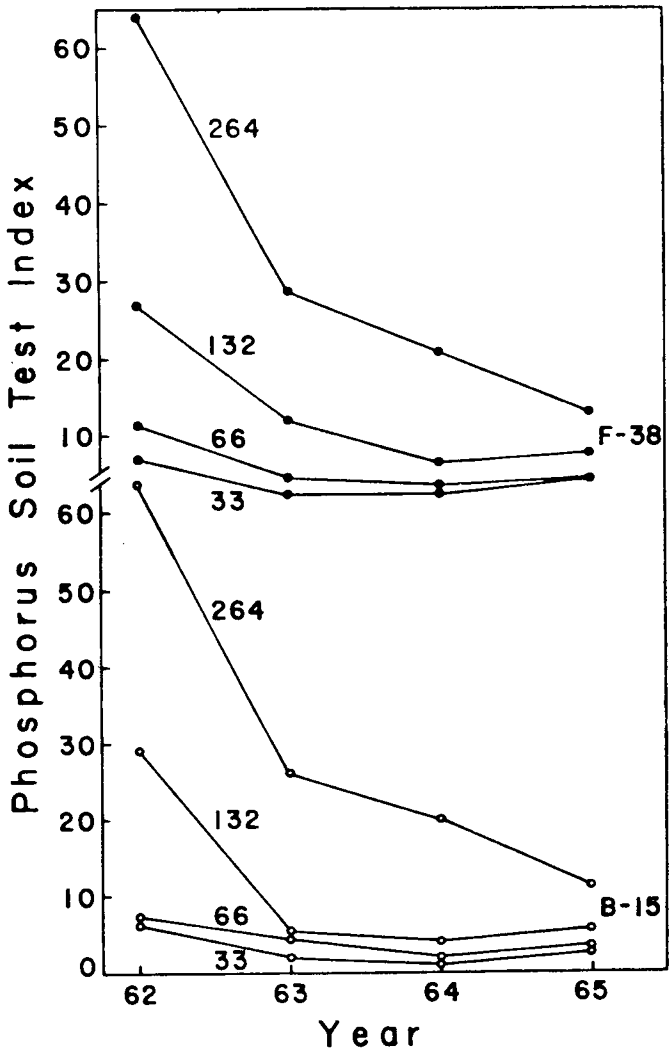
P applied lb/acre	Sampling time 10/63	5/64	Mean
1962	Soil test P index[a]		
33	2.5	3.2	2.9
66	4.2	4.4	4.3
132	10.7	11.1	10.9
264	31.7	30.1	30.9
1963			
33	6.9	8.3	7.6
66	15.7	12.8	14.2
132	22.7	21.7	22.2
264	77.7	56.3	67.0
Mean	21.5	18.5	

[a] Average of three replications. Difference between overall means for sample time not significant.

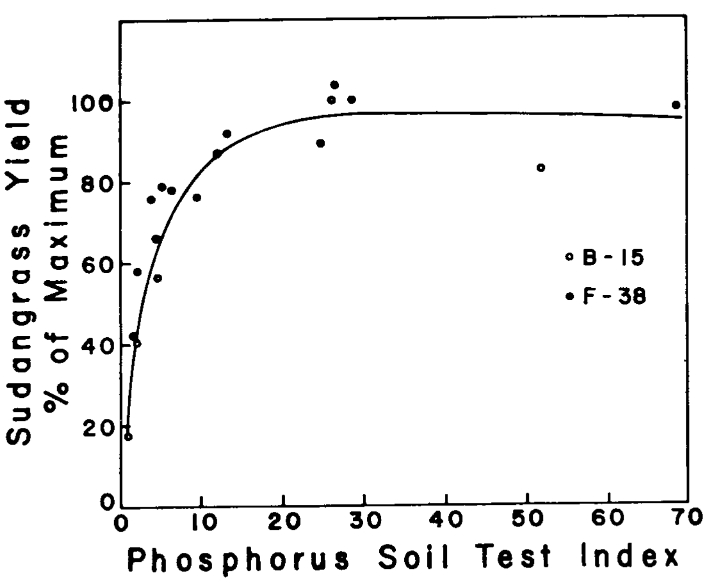
Table 8. Pounds of P per acre removed by crops

P applied lb/acre & year	B-15 1962 Beans	B-15 1963 Sudan-grass	B-15 1964 Sudan-grass	B-15 1965 Sugar beets[a]	B-15 Total	F-38 1962 Beans[b]	F-38 1963 Sudan-grass	F-38 1964 Sudan-grass	F-38 1965 Sugar beets	F-38 Total
0	0.8	1.4	2.6	12.1[c]	16.9	0.9	6.4	7.2	7.8	22.3
1962										
33	2.8	4.4	3.7	11.8	22.7	5.2	10.9	10.0	8.0	34.1
66	6.5	6.6	6.0	15.5	34.6	5.7	15.6	12.3	12.6	46.2
132	9.9	8.5	8.5	19.9	46.8	7.9	19.5	19.5	17.5	64.4
264	17.5	14.6	13.6	24.2	69.9	8.3	23.0	24.8	19.9	76.0
1963										
33		5.4	4.6	11.2	21.2		10.4	11.7	14.6	36.7
66		8.3	8.1	14.6	31.0		14.4	15.5	17.5	47.4
132		13.1	11.8	19.2	44.1		15.4	22.5	19.6	57.5
264		12.5	12.0	23.6	48.1		16.3	23.2	27.2	66.7
1964										
33			5.6	16.9	22.5			11.2	17.9	29.1
66			5.3	22.8	28.1			13.7	19.6	33.3
132			10.5	22.6	33.1			17.3	25.7	43.0
264			11.3	23.2	34.5			17.8	35.4	53.2

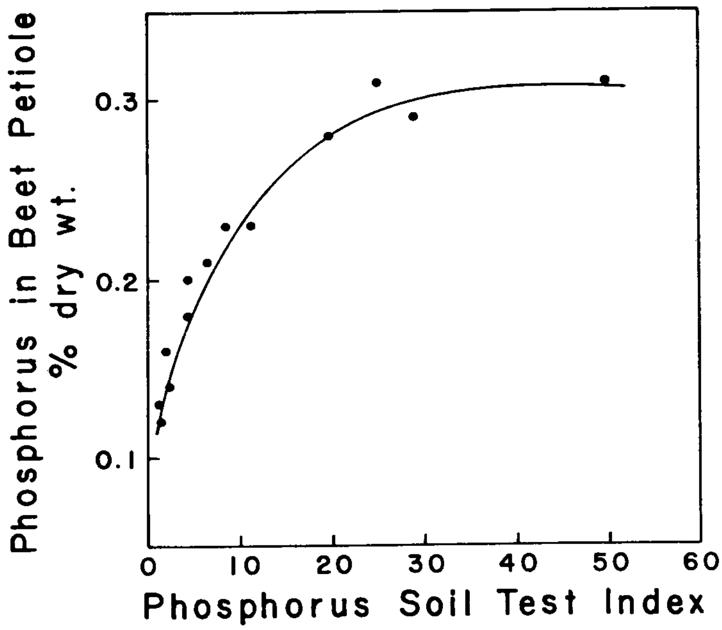
[a] Estimated low because of death of older leaves on low N residue plots.
[b] Estimated low because of the loss of many leaves due to maturity of plants at harvest.
[c] Believed to be over-estimated. See Sugar beets—1965 section of text.



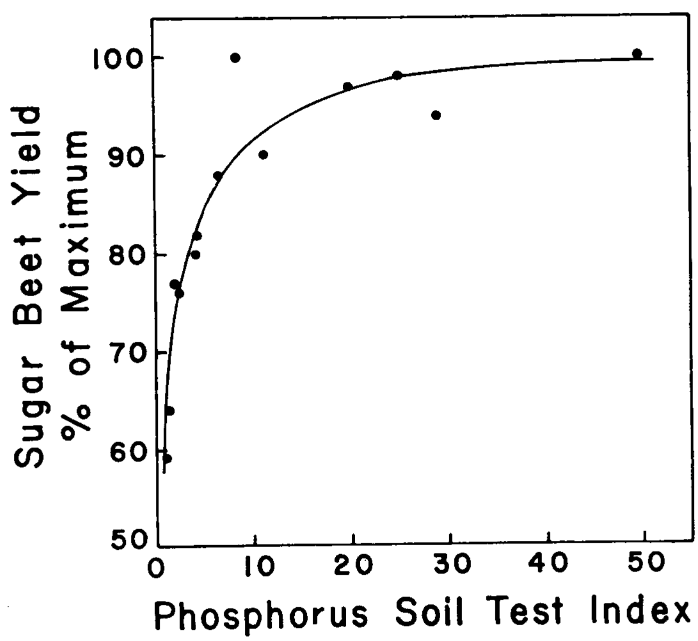
10. Effect of time on change in soil test values for plots receiving fertilizer in 1962 at the two calcareous sites, F-38 and B-15. Soil samples taken in late fall of each year.



11. Relationship between relative Sudangrass yield and soil test phosphorus, 1964 results at two locations.



12. Relationship between per cent P in beet petioles and soil test phosphorus, B-15 location.



13. Relationship between sugar beet yield and soil test phosphorus, B-15 location.

The correlation between per cent P in sugar beet petioles and soil test at F-38 was precluded by sulfur deficiency. This relationship for B-15 is shown in figure 12. The smooth curve denotes a continuous increase in per cent P with increasing soil test. The per cent P levels off above soil test 20.

The relationship between soil test and yield of beets is shown in figure 13. Figures 11 and 13 indicate that yields increase sharply as the soil test index increases to about 20. Beyond the 20 index level, yield did not increase further. These results substantiate current fertilizer recommendations: phosphorus fertilizer is generally recommended when the soil test index is 20 or below.

On this basis, a yield response to P on the noncalcareous site (D-1) was anticipated in the 1962 bean crop. But yield did increase until 1964 at this location.

It might be inferred that soil test has different meaning on the two different kinds of soils, but the difference is not believed to be truly distinctive. It will be shown later that crop responses to fertilization do not occur all of the time in the soil test range of the D-1 location. The accumulation of P above the caliche may have had some effect, but the importance of this is not easy to ascertain.

DISCUSSION

It became evident with the 1962 results that exposed calcareous subsoils could be as productive within the first season after exposure as their related noncalcareous surface soils. The important factor is the amount and kind of fertilizer elements added. The results from P fertilization are analogous to those referred to previously (34, 42). A distinctive aspect of the results reported here is the extraordinarily large amount of P required to bring about the desired effect. Addition of N and Zn is of course also required, along with K for certain crops.

The residual fertilizer effects observed in 1963 and all subsequent seasons firmly established the efficacy of a large initial investment in fertilizer P for cut lands. The data summarized in table 5 give adequate proof of this point: sugar beet yields of 28.8 and 29.7 tons per acre from 264 lb/acre P applications spaced four seasons apart provide the best single commentary on the subject. These yields contrast with 17.6 tons of beets obtained where no fertilizer P had been applied in any season.

The utility of the soil test in predicting soil P availability was also clearly established by correlation with crop yield and P uptake. An economically sound practice for establishing a high-yield cropping system on cut lands would be as follows:

1. Use soil test as a guide.
2. Plow down the recommended rate of P at the outset.
3. In subsequent seasons, apply required quantities of P to maintain the P soil test index above 20. Frequency and amount of P to apply for maintenance depend to some extent on the type of crop and the amount of crop residue returned to the soil.

Although the soil test can be invaluable in soil fertility management, the soil test result can easily be invalidated by a poor sampling. The critical problem of proper soil sampling technique cannot be overemphasized. It was shown here that dramatic results were obtained by simply sampling the soil to 10 inches to "recover" the fertilizer P instead of the earlier procedure of sampling to 6 inches only. It is obvious that the soil sample depth should be at least as deep, and preferably slightly deeper, than the lowest level the plow reaches during a crop rotation.

Land leveling to facilitate irrigation seriously complicates the problem of soil sampling. For example, soil samples in two transects were obtained from a newly leveled field of Shano silt loam. Points in the transects were 50 feet apart. The soil P indexes corresponding to successive points in one transect were: 7.6, 16.8, 16.6, 5.6, 1.0, 5.0, 14.4 and 32.8. In the other transect, 550 feet from the first, the soil test values were: 5.2, 1.6, 0.8, 1.0, 0.2, 1.0, 4.6 and 16.2.

The futility of representing such a field with a single sample of soil is readily apparent. Thus, many noncomposited samples will be needed, preferably on some type of grid system, to delineate the soil test contour levels. This approach is necessary to intelligently predict the amount of fertilizer required for top production.

The above transect data show it is uneconomical to fertilize a field as if the soil test index were uniformly either 1.0 or 20.0. Neither is it economical to base the fertilizer rate on the average soil test (8.2 in the examples given) because yield on the deep cuts would be very low. In the 11-acre field from which the transects were taken, 51% of the area had a soil test index less than 5.0.

The best solution for fertilizing leveled fields seems to be a compromise between the extent of field variation (very low soil test to very high) and the distribution of the variation (small spots versus large spots or long strips). Research results presented here indicate that after heavy P applications, wide variations in P soil fertility levels will be smoothed out because of the pronounced residual effect of fertilizer P.

The poor performance of moderate rates of P fertilizer in calcareous soils has frequently been attributed to P fixation by the lime. It is true that when soluble phosphorus compounds are added to a calcareous soil, some of the P is immediately taken out of solution by physico-chemical absorption and/or precipitation reactions. The physiological (plant) availability of these phosphorus forms is governed by the surface area and extent of mono-layer coverage (8) and by the solubility of the chemical precipitates (3, 25, 26, 28). Apparently, one of the most important phosphorus precipitates is dicalcium phosphate dihydrate. This may change to anhydrous dicalcium phosphate (26). For practical purposes, dicalcium phosphate dihydrate is considered to be insoluble, but it does have a finite solubility and may ultimately be transformed to hydroxyapatite (3) and octacalcium phosphate (24). Moreno et al. (28) seem to eliminate octacalcium phosphate as a possible reaction product, however. (In passing, it is worthy of note that there is no evidence for the formation of tricalcium phosphate in the soil.)

Hemwall (20) concludes that P enters into a broad series of calcium phosphate compounds in the soil and that these reactions are synonymous with P fixation in calcareous soils. He states that there is evidence also that P can be fixed by aluminum in the clay fractions of calcareous soils. This implies that variscite and taranakite (aluminum phosphate minerals), which have been postulated for acid soils (6, 17, 18, 26), may also occur in calcareous soils. Since calcareous soils contain free iron oxide, one could postulate the formation of strengite (iron phosphate mineral) on the same basis. Such hypotheses remain to be substantiated.

Whether or not P fixation is an important phenomenon in calcareous soils is a matter of definition. If fixation is defined by solubility, then a line must be drawn between closely related calcium phosphates. If fixation is defined by physiological availability, the concept has little relevance to calcareous soils, since the most important form of soil phosphorus is apparently dicalcium phosphate dihydrate (3, 25, 28). The latter has been shown to have definite, though limited value as a phosphorus fertilizer (35, 39). The experimental results presented here indicate that P fixation, or decrease in physiological availability, is not a serious problem in the calcareous soils studied. These results agree with those of others who have investigated P relationships of calcareous soils. (See *Review of Literature* section.)

The expression "soil test index" has been used throughout this bulletin to avoid certain ambiguities associated with the habit of referring to soil test results in terms of "lb P/acre available." By the soil test procedure followed here, a P soil test index of 20 is literally 20 parts of P per two million parts of soil. The customary practice of referring to this as "20 lb P/acre available" is erroneous for two reasons.

First, in sampling the full plow layer, the soil mass sampled may greatly exceed 2,000,000 lb soil per acre 6 inches—the basis of the older nomenclature. Second, the number obtained from chemical analysis of the soil is not a measure of the absolute quantity of available P. It is probable that the soil test procedure does not represent all the forms of inorganic P that may become available during the season. And it can't represent the organic P which will become available through degradation of organic matter.

The soil test index is simply a quantity of P that is proportional to the total amount of P that would be physiologically available at the time when the test is made. The proportionality between the soil test P and total available P is determined by correlation with field experiments.

Although the brief results on fertilizer placement shown here seem to favor broadcast application over banding, the evidence is not conclusive. Unless there is some "starter" effect from P that is banded at planting time, this procedure probably has no special merit over broadcasting and plowing under. The evidence does indicate that timing is not critical if the fertilizer is broadcast and plowed before planting. For alfalfa and certain other perennial crops, a sound practice might be to anticipate the total P fertilizer needs of a field for the lifetime of the crop (4-6 years) and plow it all down at the time of crop establishment.

PHOSPHORUS FERTILIZER RESPONSE FREQUENCY DISTRIBUTION

The results of field experiments involving phosphorus in central Washington were summarized for the period 1957 to 1966. The yield increases over the checks were categorized according to the soil test level before the respective trials were established. All experiments included were replicated and contained phosphorus fertilizer rates and usually one or more other variables such as K rates, N rates, boron, zinc, etc. Most of the results have been published but some have not.

Table 9 shows results in terms of response frequency distributions at the various soil test P levels. The evidence indicates a 100% probability of response to P in the soil test category 0-5. The soil test category 5-15 indicates a 64% response probability. Categories 15-20 and 20+ indicate zero probability for responses to P fertilizer.

The category 0-5 has heavier representation among the various experiments because most field sites were selected on the basis of low soil test. The amount of fertilizer P required for maximum yields for the 0-5 category of table 9 averaged 133 lb P/acre for all crops. P requirements for best results in category 5-15 averaged 88 lb P/acre. Full yield potential was not achieved in all cases for one reason or another. Therefore, the absolute amount of P that gave maximum yield varied between experiments in the same category.

Although table 9 indicates a zero probability of crop response to P in the category 15-20, routine fertilizer recommendations are made up to the 20 level. This provides a safety factor for borderline fertility situations and some protection against poor soil sampling.

Subdividing the 5-15 category into two categories would give a more complete picture of P response frequencies. More experienced observations in the whole range 5 to 20+ also are needed. Economic responses to P fertilizer in the 20+ category are not entirely improbable. Such cases have been reported under rather special circumstances; e.g., very high yields of potatoes produced with extra-high rates of N, P and K fertilizers.

One area that should be investigated is the effect of fertilizer P on crops where the soil test is very high. Some growers of high value crops such as grapes, hops, potatoes, mint, etc. habitually apply liberal amounts of P fertilizer whether or not there is an indicated need for it. Under these conditions of continuous heavy usage, the probability of a positive response to P fertilizer is indeed very low. Actually, some adverse side effects may develop (especially zinc deficiency) from a super-abundance of soil phosphorus.

Table 9. Crop responses to phosphorus fertilizer; frequency distributions in four soil test categories[a]

Crop	Year	Area	Yield increase from P applied[b] Soil test category 0-5	5-15	15-20	20+
Peas	1957	Quincy				0
"	"	Othello		500		
"	"	Pasco			0	
"	"	Royal Slope		1020		
"	1964	Royal City	1745			
Beans	1957	NW Frenchman Hills	1250[c]			
"	"	Mesa				0
"	"	Othello		350		
"	"	Royal Slope	1540			
"	"	Moses Lake			0	
"	"	Quincy		0		
"	1960	Connell	1453			
"	"	Wahluke Slope	1050			
"	"	Othello	1800			
"	"	Royal Slope			0	
"	1961	" "		700		
"	"	Wahluke Slope	2850			
Potatoes	1958	Kennewick			0	
"	"	Mesa		0		
"	"	Moses Lake				0
"	1960	Royal Slope		70		
"	"	Wahluke Slope	330			
"	1962	" "				0
Alfalfa	1964	Soap Lake		2140[d]		
"	"	Royal City	3200[d]			
"	"	Othello	3600[e]			
"	"	Eltopia	5400[f]			
Total responses[g]			18	7	0	0
Total experiments[g]			18	11	4	4
Response probability			100%	64%	0%	0%

[a] A summary of field experimental results for the period 1957 to 1966. Crop responses where indicated were statistically significant. Data for period 1957 to 1962 have been published (9, 10, 11, 12) except for item[c].
[b] Potato yields in cwt/acre. All others in lb/acre. Yield shown is minus check plot yield.
[c] Data courtesy L. C. Boawn.
[d] First cutting only.
[e] Two cuttings.
[f] Three cuttings.
[g] Includes all above experiments plus results in this report.

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APPENDIX

Statistical analyses were performed on material yield but not on plant nutrient content. Treatment effects were statistically significant according to the analysis of variance except where noted otherwise. Indications of experimental error are given by the standard deviation (Sd) and coefficient of variation (CV). An LSD may be calculated, if desired, using the standard deviation as:

$$LSD = t\ (2Sd/n)^{1/2}$$

where t is the tabled value at any desired confidence limit and n is the number of replications.

Details on supplementary fertilizers, planting dates and other management practices are included in text tables 2 and 3 and the methods section.

Table A1. The yield of beans, P content of tops and P uptake for beans grown at B-15 as affected by fertilizer treatments—1962

Treatment lb P/acre	Bean yield lb/acre	P content of tops, %[a]	P uptake, lb/acre[b]
0	471	.143	.8
33	1475	.182	2.8
66	2659	.258	6.5
132	3217	.320	9.9
264	3359	.362	17.5
132	3169		
33	1695		
132	2475		
Sd=	256		
C.V.=	11.5%		

[a] Whole plant basis, sampled August 1.
[b] Whole plant basis, sampled September 6.

Table A2. The yield of beans, P content of tops and P uptake for beans grown at F-38 as affected by fertilizer treatments—1962

Treatment lb P/acre	Bean yield lb/acre	P content of tops, %[a]	P uptake, lb/acre[b]
0	385	.173	.9
33	1887	.287	5.2
66	2109	.303	5.7
132	2157	.329	7.9
264	1649	.331	8.3
132	2001	.342	
Sd=	296		
C.V.=	6.0%		

[a] Whole plant basis, sampled July 31.
[b] Used July 31 sample for estimates because August 31 sample time too late to include all leaves.

Table A3. The yield of beans, P content of tops and P uptake for beans grown at D-1 as affected by fertilizer treatments—1962[a]

Treatment lb P/acre	Bean yield lb/acre	P content of tops, %[b]	P uptake, lb/acre[c]
0	2244	.356	22.2
11	2585	.355	24.7
22	2439	.380	26.6
44	2107	.372	23.9
88	2460	.380	29.2
22	2330	.372	
Sd	111		
C.V.	4.7%		

[a] According to analysis of variance, treatment effects were not significant.
[b] Whole plant sampled July 31.
[c] Whole plant sampled August 31.

Table A4. The yield, P content and P uptake for Sudangrass grown at B-15 as affected by rate and time of fertilizer application—1963[a]

Treatment, lb P/acre	Forage yield tons/acre[b]	P content, %[c]	P uptake, lb/acre[d]
0	.69	.104	1.4
33	1.90	.116	4.4
66	2.75	.124	6.6
132	3.19	.136	8.5
264	4.56	.167	14.6
33	2.39	.115	5.4
66	3.01	.142	8.3
132	4.10	.160	13.1
264	3.84	.168	12.5
132	4.81	.179	16.3
Sd=	0.55		
C.V.=	16.5%		

[a] According to analysis of variance treatment effects were not significant.
[b] Total of 3 cuttings. See Table 3, methods section, for dates.
[c] Mean of all cuttings.
[d] Total of all cuttings.

Table A5. The yield, P content and P uptake for Sudangrass grown at F-38 as affected by rate and time of fertilizer application—1963

Treatment, lb P/acre	Forage yield ton/acre[a]	P content, %[b]	P uptake, lb/acre[c]
0	2.61	.118	6.4
33	4.12	.130	10.9
66	4.96	.154	15.6
132	5.19	.186	19.5
264	5.99	.194	23.0
33	3.44	.150	10.4
66	4.07	.175	14.4
132	4.28	.179	15.4
264	4.13	.198	16.3
132	5.52	.202	21.8
Sd=	0.40		
C.V.=	8.66%		

[a] Total of 3 cuttings. See Table 3, methods section, for dates.
[b] Mean of all cuttings.
[c] Total of all cuttings.

Table A6. The yield, P content and P uptake for Sudangrass grown at D-1 as affected by rate and time of fertilizer application—1963

Treatment, lb P/acre	Forage yield ton/acre[a]	P content, %[b]	P uptake, lb/acre[c]
0	5.52	.197	21.5
33	5.82	.200	22.8
66	5.77	.203	22.6
132	5.85	.203	24.3
264	6.01	.226	25.7
33	5.95	.208	24.2
66	5.31	.208	21.4
132	5.56	.225	23.9
264	6.48	.224	26.6
132	5.91	.241	27.0
Sd=	0.45		
C.V.=	7.72%		

[a] Total of 3 cuttings. See Table 3, methods section, for dates.
[b] Mean of all cuttings.
[c] Total of all cuttings.

Table A7. The yield, P content and P uptake for Sudangrass grown at B-15 as affected by rate and time of P fertilizer application—1964

Treatment, lb P/acre	Forage yield tons/acre[a]	P content, %[b]	P uptake, lb/acre[a]
0	.62	.105	1.40
33	1.49	.116	3.70
66	2.46	.113	6.02
132	2.93	.135	8.50
264	3.72	.168	13.58
33	2.09	.103	4.63
66	2.69	.139	8.13
132	3.23	.142	11.83
264	3.09	.180	12.01
33	2.10	.120	5.59
66	1.78	.136	5.32
132	3.08	.154	10.52
264	3.11	.164	11.30
132	3.64	.205	16.19
Sd=	0.36		
C.V.=	13.5%		

[a] Total of two cuttings.
[b] Mean of two cuttings.

Table A8. The yield, P content and P uptake for Sudangrass grown at F-38 as affected by rate and time of P fertilizer application—1964

Treatment, lb P/acre	Forage yield tons/acre[a]	P content, %[b]	P uptake, lb/acre[a]
0	2.15	.164	5.90
33	2.98	.165	9.97
66	3.88	.163	12.32
132	4.47	.221	19.54
264	5.13	.244	24.85
33	4.01	.151	11.72
66	4.69	.169	15.46
132	5.32	.215	22.50
264	5.05	.230	23.19
33	3.94	.143	11.25
66	4.08	.170	13.71
132	4.27	.199	17.35
264	4.45	.202	17.85
132	4.28	.257	23.54
Sd=	0.55		
C.V.=	14.1%		

[a] Total of two cuttings.
[b] Mean of two cuttings.

Table A9. The yield, P content and P uptake for Sudangrass grown at D-1 as affected by rate and time of P fertilizer application—1964

Treatment, lb P/acre	Forage yield tons/acre[a]	P content, %[b]	P uptake, lb/acre[a]
0	5.98	.219	25.28
11	6.03	.220	26.16
22	5.96	.217	24.83
44	6.09	.237	29.44
88	5.92	.243	28.09
11	6.08	.229	27.13
22	6.19	.218	26.05
44	6.30	.225	27.62
88	6.31	.250	30.36
11	6.13	.220	26.13
22	6.47	.218	26.87
44	6.35	.231	28.69
88	7.05	.250	34.10
44	7.48	.272	39.95
44	7.17	.250	34.89
Sd=	.44		
C.V.=	8.4%		

[a] Total of two cuttings.
[b] Mean of two cuttings.

Table A10. Yield of sugar beets, % sugar in root and % P in petiole at B-15 as affected by fertilizer treatments—1965

Treatment lb P/acre	Yield of roots tons/acre	Sugar %	June 30 Petiole % P
0	17.60	14.1	.134
33	19.10	14.3	.122
66	23.01	15.6	.156
132	24.38	14.4	.201
264	28.82	15.7	.280
33	22.54	15.2	.145
66	23.95	15.6	.182
132	29.78	16.0	.230
264	29.06	15.8	.312
33	26.21	15.6	.210
66	26.81	15.6	.230
132	27.97	16.7	.290
264	29.78	16.0	.314
132	30.76	15.9	.315
264	29.69	14.4	.310
Sd=	2.18		
C.V.=	8.11%		

Table A11. Yield of sugar beets, % sugar in root and % P in petiole at F-38 as affected by fertilizer treatments—1965

Treatment lb P/acre	Yield of roots tons/acre	Sugar %	June 30 Petiole % P
0	14.96	14.0	.156
33	17.05	14.0	.155
66	20.34	14.8	.173
132	21.70	14.8	.249
264	23.26	14.7	.275
33	18.91	14.5	.156
66	22.52	14.9	.189
132	25.92	14.8	.255
264	28.67	14.9	.285
33	23.07	14.7	.148
66	25.96	14.6	.225
132	28.08	15.0	.296
264	30.76	14.9	.310
132	27.24	15.1	.351
Sd=	3.18		
C.V.=	13.54%		

Table A12. Yield (season total) and P content (second cutting only) of alfalfa on oven-dry basis as affected by P fertilizer rate

P applied lb/acre	1965 Yield tons/acre	P %	P applied lb/acre	1966 Yield tons/acre	P %
0	1.73	.17	0	1.23[a]	.17
22.5	3.46	.21	22.5	3.20	.22
45	4.29	.23	45	3.90	.24
90	5.03	.24	90	5.23	.26
135	5.52	.26	135	5.70	.27
			90[b]	5.05	.27
			180[c]	6.46	.30
			225[d]	6.03	.29
Sd=	0.49			0.51	
C.V.=	18.6%			9.8%	

[a] Estimated from first cutting.
[b] Received 90 lb P/acre in 1965.
[c] Received 90 lb P + 3 lb B per acre in 1965.
[d] Received 90 lb P + 6 lb B per acre in 1965.